(U) X-Radiographic Parallax Reduction with 3D-Printed Fixturing

Michael J. Rodriguez
Walter Rose
Lawrence J. D'Aries

US Army CCDC
Armaments Center

Building 908
Picatinny Arsenal, NJ 07806

Michael.j.rodriguez60.civ@mail.mil
Walter.s.rose5.civ@mail.mil
Lawrence.j.daries.civ@mail.mil

(U) Abstract: With the increasing viability and availability of 3D printers, the potential for precise and reliable fixture design is now possible. In this paper we explore the construction and performance of a 3D printed fixture used for Radiographic Non-Destructive Testing of aircraft countermeasure flares. The fixture is designed to minimize parallax, to be minimally intrusive to the resulting radiographic image, and to incorporate an intrinsic measure of safety in handling and positioning the item for inspection in order to ensure the highest quality product gets to the warfighter.

(U) Research Innovation and Objective(s): The speed and relatively inexpensive cost of 3d printers allow for precise fixture design to be used in radiographic testing applicable to a wide variety of test items. The fixture design explored here serves to minimize parallax for optimal inspection conditions, and allows for maximum loading, while being minimally intrusive and increasing the overall safety of handling and positioning test items for inspection.

(U) Impacts on Warfighter Mission: Improving radiographic quality and increasing the safety of non-destructive testing allows for thorough inspection of air countermeasure flares while allowing for maximum test item throughput in order to support our mission to provide the best quality material for survivability and effectiveness for the warfighter in the air.

(U) Keywords: 3D Printer, Non-Destructive Testing, NDT, X-Ray, Parallax

1. (U) Introduction

(U) Radiographic testing is a non-destructive testing technique which allows for the detection of subsurface flaws. It is applicable to most materials and can reveal fabrication and underlying assembly errors. Another advantage of radiographic testing is its ability to reveal structural discontinuities. [1] Fixture design is an important part of the radiographic testing process which allows for reliable and precise radiographic interpretation. With the increasing viability and availability of 3D printers, the potential for precise and reliable fixture design is now possible on an affordable and timely basis. In this paper we describe a fixture design which minimizes parallax while reducing the probability for errors in loading.

2. (U) Method

2.1 (U) Theory

(U) Parallax is defined to be the apparent displacement of an object as seen from two different points that are not on a line with the object. [2] The hallmark sign of parallax is the appearance of blurred edges as opposed to dark uniform edges on a given item. Parallax becomes more apparent the farther an object is placed from beam center. Rotating the object by an angle θ relative to the beam center, will allow for parallax reduction and increase in radiographic clarity.

(U) Qualitatively, we would expect the rotation angle θ to be a monotonically increasing function with respect to the distance from the center. We can derive an equation (1) for the dependent variable θ referring to figure 1 below.

$$\theta = \tan^{-1}\frac{x}{y} \quad (1)$$

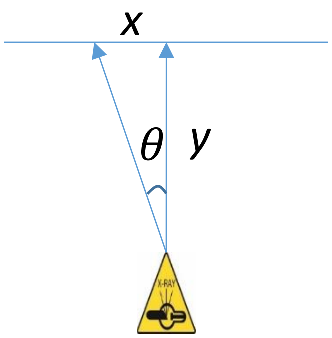

Figure 1. Geometry[1]

[1] X Ray Source Image obtained from Queen's University Department of Chemistry https://www.chem.queensu.ca/safety/signage

(U) In equation (1) θ represents the rotation angle, x represents the distance from the center of the fixture and y is the source to detector distance. For a given geometry, the source to detector distance, y, will be fixed. Therefore our rotation angle is solely a function of the distance x. Illustrated below is a graph of the rotation angle θ as a function of x, the distance from beam center. For the graph in figure 2 below, y is set to 706 mm. As discussed above the graph confirms the monotonic increasing nature of the rotation angle as a function of x.

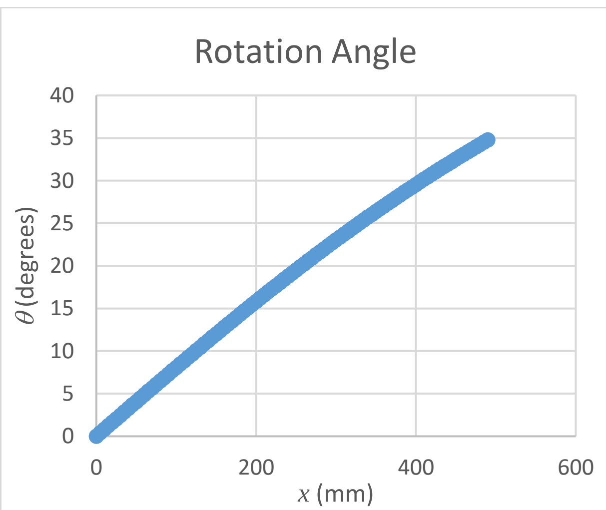

Fig. 2 Graph of rotation angle versus position

(U) When an object is placed directly normal to the center of the beam path, the distance from the center is trivially zero, and so the rotation angle is zero. Note how both equation (1) and Figure 2 are consistent with this observation. As mentioned previously, as the distance from the center increases, the rotation angle θ increases. Theoretically, one can imagine an object placed an infinite distance away from the center of the beam. That is, let us consider the mathematical limit as x increases without bound. Mathematically this can be described as,

$$\theta = \lim_{x\to\infty} \tan^{-1}\frac{x}{y} = \frac{\pi}{2}$$

In practical terms this verifies that our rotation angle will always lie in the interval,

$$0 \leq \theta < 90°$$

as one might anticipate.

2.1.1 (U) Inverse Square Law

(U) The intensity of radiation follows Newton's inverse square law. [3] In our setup we have assumed that the item is against the detector. This geometry yields the trivial magnification of one. Therefore, both the Source to Object Distance (SOD) and Source to Detector Distance (SDD) are equivalent. As before, we can take the limit as the distance between source and detector becomes infinite. As one might expect, the limiting process yields a rotation angle of zero. This confirms our intuition that if an object is placed an infinite distance from the source the need for rotation would be eliminated. Mathematically,

$$\theta = \lim_{y\to\infty} \tan^{-1}\frac{x}{y} = 0$$

Illustrated below is a graph of the rotation angle θ as a function of y, the source to detector distance. For the graph in figure 3 below, x is set to 50.8 mm. The graph confirms the monotonic decreasing nature of the rotation angle as a function of y.

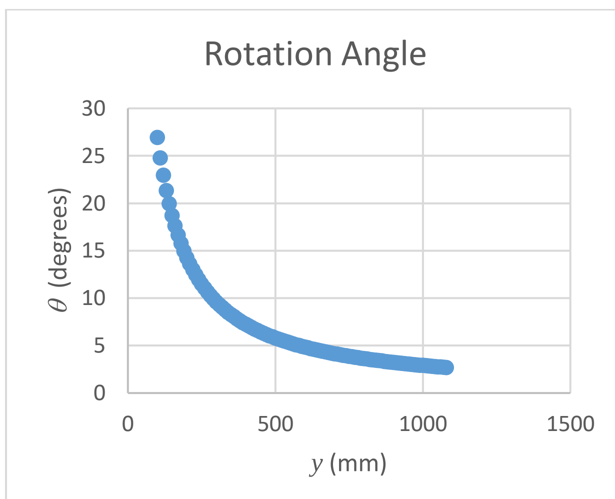

Fig. 3 Graph of rotation angle versus SDD

2.1.2 (U) Case Study: M206 Flare

(U) As a case study, we will consider a specific example so that the technique can be defined and replicated while keeping the discussion general to allow for a variety of fixture design ideas. Recently, the radiographic laboratory received hundreds of air countermeasure flares for radiographic inspection. These flares are part of a family of advanced IR decoy flares designed for use by the Army aircraft and helicopters to meet advanced threats in current and future operational environments. [4]

(U) A need to create a fixture was identified in the discussion above. The three primary requirements for this fixture were 1) to support these munitions in the appropriate orientation relative to the x-ray source, 2) to be minimally intrusive to the radiographic image result, and 3) to include a measure of safety in handling and positioning the munitions for inspection.

(U) A digital model was required to be 3D printed by using dedicated Computer-Aided Drafting (CAD) software to incorporate the aforementioned angle requirements at the fundamental design level (Figure 4). A non-corrected model was also produced to highlight the advantages gained by introducing parallax correction at the design stage.

(U) Good fixture design requires a minimum of radiographic interference with the signal. Considered for this 3D print were the most common and economical materials: acrylonitrile butadiene styrene (ABS), polylactic acid (PLA), polyethylene terephthlalate (PET), polyvinyl alcohol (PVA), nylon, and some hybrids. ABS was chosen for use due to its suitable combination of linear attenuation coefficient of x-rays (0.189 ± 0.005 @ 60 kV), low density (1.09 g/cm^3) [5], rigidity, strength and ready availability on the commercial market. Realize that only the very bottom of the flare is being obstructed by these wells. Subsequent radiographs revealed that indeed the bottom was unobstructed and can be reliably analyzed for defects.

(U) Radiographic inspection of multiple items requires handling by humans, so safety was a concern in the fixture's design. The design incorporated individual wells into which each flare is intended to be placed. The wells were designed to be deep enough (0.6" by empirical test) to disallow tipping of the test item due to random and minor events during handling.

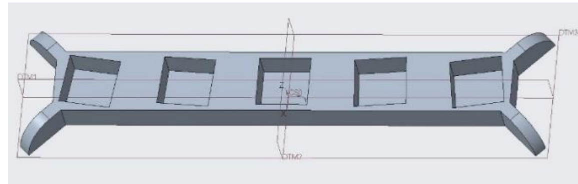

Fig. 4 CAD drawing of fixture

(U) Once the model was created and verified for use it was converted to a stereolithographic image for printing. 3D creation was accomplished by Fused Deposition Modelling (FDM) technology on a TAZ-6 3D printer. The fixture is 9.56"L x 1.38"W, not including the individual stabilizers which extend 1.0"L on a 45° extrusion angle at each corner. The overall thickness of the fixture is 0.65" and the wells are 0.60" deep. Optimal well spacing placed the adjacent well outside the expected maximum scatter angle from the nearest edge of the incident munition holding well.

(U) Consider a source to detector distance of 706 mm and a fixture made of five wells which is diagrammed below. Figure 5 contains a picture of the fixture that contains corrections for parallax.

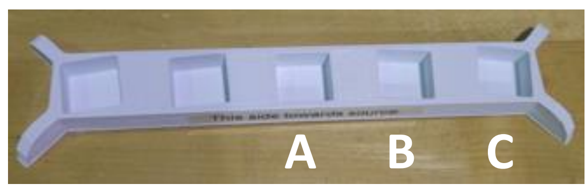

Figure 5. Fixture designed to minimize parallax

3. (U) Results & Discussion

(U) Using formula (1) we can now calculate the rotation angle for each well. The results are displayed in table (1) with reference to figure 5.

Separation	Distance	Angle
AA	0 mm	0°
AB	50.8 mm	4.11°
AC	101 mm	8.14°

Table (1)

(U) Acquisition was performed using a North Star Imaging x5500 x-ray apparatus. This system includes a YXLON Feinfocus FXE x ray source capable of producing up to 225 kV with a PerkinElmer XRD 1620 detector. Tube voltage was set to 125 kV with a current of 710 μA. Detector gain was set at 0.5 pF with a frame rate of 6 fps.

(U) Figure 6 contains the flares in a fixture where the wells are not corrected for parallax. Figure 7 contains a radiograph for flares in a fixture where the wells are corrected for parallax. Visually, one can detect a discernable difference in the appearance of the edges of each item. The difference becomes more apparent the farther the item is from the center, as anticipated by the theory.

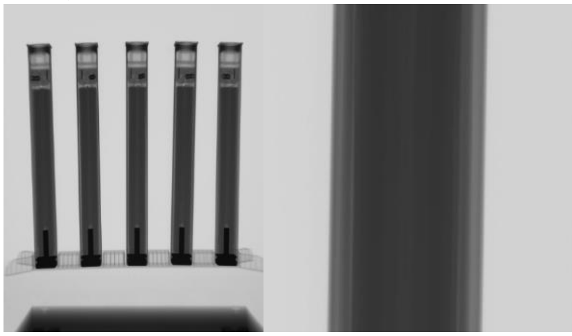

Figure 6. Original Fixture

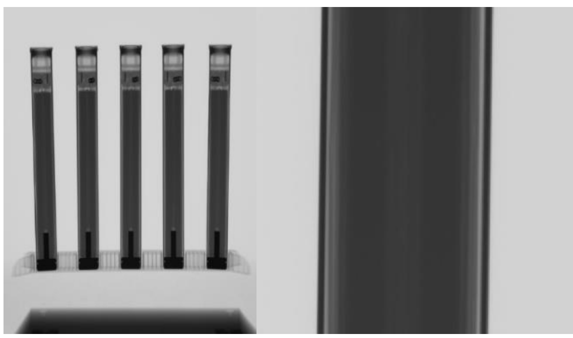

Figure 7. Fixture designed to minimize parallax

4. (U) Conclusion

(U) X-Radiographic parallax can be reduced greatly by rotating the item when placed at an angle relative to beam center. Further 3d printed fixtures using this system will be explored with the emphasis on improving radiographic image quality and improving safety.

4. (U) Acknowledgments

(U) Thank you to Brian McNannna for assisting in developing and qualifying the radiographic technique.

References

1. T.A.S.F.N. Testing, Radiographic Testing Classroom Training Book, Columbus, OH: Personnel Training Publications, 2016
2. N.S. Imaging, Digital Radiography & Basic Computed Tomography Per Industry Requirements, Rogers, MN: NSI, 2018
3. "Radiographic Inspection-Formula based on Newton's Inverse Square Law", [Online]. Available: http://www.ndeed.org/GeneralResources/Formula/RTFormula/InverseSquare/InverseSquareLaw.htm
4. "PdL Support Systems," [Online]. Available: https://www.pica.army.mil/pmccs/SupportMunitions/Flares/CounterMeasures.html
5. Danail Ivanov, "Suitability of low density materials for 3D printing of physical breast phantoms", Physics in Medicine & Biology, vol. 63, p. 14, 2018.